

The one loop contributions to $c(t)$ electric dipole moment in the CP violating BLMSSM

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Abstract

In the CP violating supersymmetric extension of the standard model with local gauged baryon and lepton symmetries (BLMSSM), there are new CP violating sources which can give new contributions to the quark electric dipole moment (EDM). Considering the CP violating phases, we analyze the EDMs of the quarks c and t . We take into account the contributions from the one loop diagrams. The numerical results are analyzed with some assumptions on the relevant parameter space. The numerical results for the c and t EDMs can reach large values.

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I. INTRODUCTION

The CP violation found in the K- and B system [1] can be well explained in the standard model. It is well known that, the electric dipole moment(EDM) of elementary particle is a clear signal of CP violation[2]. The Cabbibo-Kobayashi-Maskawa(CKM) phase is the only source of CP violation in the SM, which has ignorable effect on the EDM of elementary particle. In the SM, even to two loop order, the EDM of a fermion does not appear, and there are partial cancelation between the three loop contributions[3]. If EDM of an elementary fermion is detected, one can confirm there are new CP phases and physics beyond the SM.

Though SM has obtained large successes with the detection of the lightest CP-even Higgs h^0 [4], it is unable to explain some phenomena. Physicists consider the SM should be a low energy effective theory of a large model. The minimal supersymmetric extension of the standard model(MSSM) is very favorite and people have been interested in it for a long time[5]. There are also many new models beyond the SM, such as $\mu\nu$ SSM[6]. Generally speaking, the new models introduce new CP-violating phases that can affect the EDMs of fermions, $B^0 - \bar{B}^0$ mixing et al. The EDMs of electron and neutron are strict constraints on the CP-violating phases[7]. In the models beyond SM, there are new CP-violating phases which can give large contributions to electron and neutron EDMs[8]. To make the MSSM predictions of electron and neutron EDMs under the experiment upper bounds, there are three possibilities[9]: 1 the CP-violating phases are very small, 2 varies contributions cancel with each other in some special parameter spaces, 3 the supersymmetry particles are very heavy at several TeV order.

Taking into account the local gauged B and L , people obtain the minimal supersymmetric extension of the SM, which is the so called BLMSSM[11]. The authors in Ref.[10] first proposed BLMSSM, where they studied some phenomena. At TeV scale, the local gauge symmetries of BLMSSM breaks spontaneously. Therefore, in BLMSSM R-parity is violated and the asymmetry of matter-antimatter in the universe can be explained. We have studied the lightest CP-even Higgs mass and the decays $h^0 \rightarrow VV$, $V = (\gamma, Z, W)$ [12] in the BLMSSM, where some other processes[13] are also researched. Taking the CP-violating phases with nonzero values, the neutron EDM, lepton EDM and $B^0 - \bar{B}^0$ mixing are researched in this model[14].

From neutron experimental data, the bounding of top EDM is analyzed[15]. Taking into

account the precise measurements of the electron and neutron EDMs, the upper limits of heavy quark EDMs are also discussed[16]. The upper limits on the EDMs of heavy quarks are researched from e^+e^- annihilation[17]. In the CP-violating MSSM, the authors study c quark EDM including two loop gluino contributions[18]. There are also other works on the c quark EDM[19]. Considering the pre-existing works, the upper bounds of EDMs for c and t are about $d_c < 5.0 \times 10^{-17} e.cm$ and $d_t < 3.06 \times 10^{-15} e.cm$. In this work, we calculate the EDMs of charm quark and top quark in the framework of the CP-violating BLSSM. At low energy scale, the quark chromoelectric dipole moment(CEDM) can give important contributions to the quark EDM. So, we also study the quark CEDM with the renormalization group equations.

In Section 2, we briefly introduce the BLSSM and show the needed mass matrices and couplings, after this introduction. The EDMs(CEDMs) of c and t are researched in Section 3. In Section 4, we give out the input parameters and calculate the numerical results. The last Section is used to discuss the results and the allowed parameter space.

II. THE BLSSM

Considering the local gauge symmetries of B(L) and enlarging the local gauge group of the SM to $SU(3)_C \otimes SU(2)_L \otimes U(1)_Y \otimes U(1)_B \otimes U(1)_L$ one can obtain the BLSSM model[11]. In the BLSSM, there are the exotic superfields including the new quarks $\hat{Q}_4 \sim (3, 2, 1/6, B_4, 0)$, $\hat{U}_4^c \sim (\bar{3}, 1, -2/3, -B_4, 0)$, $\hat{D}_4^c \sim (\bar{3}, 1, 1/3, -B_4, 0)$, $\hat{Q}_5^c \sim (\bar{3}, 2, -1/6, -(1+B_4), 0)$, $\hat{U}_5 \sim (3, 1, 2/3, 1+B_4, 0)$, $\hat{D}_5 \sim (3, 1, -1/3, 1+B_4, 0)$, and the new leptons $\hat{L}_4 \sim (1, 2, -1/2, 0, L_4)$, $\hat{E}_4^c \sim (1, 1, 1, 0, -L_4)$, $\hat{N}_4^c \sim (1, 1, 0, 0, -L_4)$, $\hat{L}_5^c \sim (1, 2, 1/2, 0, -(3+L_4))$, $\hat{E}_5 \sim (1, 1, -1, 0, 3+L_4)$, $\hat{N}_5 \sim (1, 1, 0, 0, 3+L_4)$ to cancel the B and L anomalies.

With the detection of the lightest CP even Higgs h^0 at LHC[4], Higgs mechanism is very convincing for particle physics, and BLSSM is based on the Higgs mechanism. The introduced Higgs superfields $\hat{\Phi}_L(1, 1, 0, 0, -2)$, $\hat{\varphi}_L(1, 1, 0, 0, 2)$ and $\hat{\Phi}_B(1, 1, 0, 1, 0)$, $\hat{\varphi}_B(1, 1, 0, -1, 0)$ break lepton number and baryon number spontaneously. These Higgs superfields acquire nonzero vacuum expectation values (VEVs) and provide masses to the exotic leptons and exotic quarks. To make the heavy exotic quarks unstable the superfields $\hat{X}(1, 1, 0, 2/3+B_4, 0)$, $\hat{X}'(1, 1, 0, -(2/3+B_4), 0)$ are introduced

in the BLMSSM.

The $SU(2)_L$ doublets H_u , H_d obtain nonzero VEVs v_u , v_d ,

$$H_u = \begin{pmatrix} H_u^+ \\ \frac{1}{\sqrt{2}}(v_u + H_u^0 + iP_u^0) \end{pmatrix}, \quad H_d = \begin{pmatrix} \frac{1}{\sqrt{2}}(v_d + H_d^0 + iP_d^0) \\ H_d^- \end{pmatrix}. \quad (1)$$

The $SU(2)_L$ singlets Φ_B , φ_B and Φ_L , φ_L obtain nonzero VEVs v_B , \bar{v}_B and v_L , \bar{v}_L respectively,

$$\begin{aligned} \Phi_B &= \frac{1}{\sqrt{2}}(v_B + \Phi_B^0 + iP_B^0), & \varphi_B &= \frac{1}{\sqrt{2}}(\bar{v}_B + \varphi_B^0 + i\bar{P}_B^0). \\ \Phi_L &= \frac{1}{\sqrt{2}}(v_L + \Phi_L^0 + iP_L^0), & \varphi_L &= \frac{1}{\sqrt{2}}(\bar{v}_L + \varphi_L^0 + i\bar{P}_L^0). \end{aligned} \quad (2)$$

Therefore, the local gauge symmetry $SU(2)_L \otimes U(1)_Y \otimes U(1)_B \otimes U(1)_L$ breaks down to the electromagnetic symmetry $U(1)_e$.

We show the superpotential of BLMSSM [12]

$$\begin{aligned} \mathcal{W}_{BLMSSM} &= \mathcal{W}_{MSSM} + \mathcal{W}_B + \mathcal{W}_L + \mathcal{W}_X, \\ \mathcal{W}_B &= \lambda_Q \hat{Q}_4 \hat{Q}_5^c \hat{\Phi}_B + \lambda_U \hat{U}_4^c \hat{U}_5 \hat{\varphi}_B + \lambda_D \hat{D}_4^c \hat{D}_5 \hat{\varphi}_B + \mu_B \hat{\Phi}_B \hat{\varphi}_B \\ &\quad + Y_{u4} \hat{Q}_4 \hat{H}_u \hat{U}_4^c + Y_{d4} \hat{Q}_4 \hat{H}_d \hat{D}_4^c + Y_{u5} \hat{Q}_5^c \hat{H}_d \hat{U}_5 + Y_{d5} \hat{Q}_5^c \hat{H}_u \hat{D}_5, \\ \mathcal{W}_L &= Y_{e4} \hat{L}_4 \hat{H}_d \hat{E}_4^c + Y_{\nu 4} \hat{L}_4 \hat{H}_u \hat{N}_4^c + Y_{e5} \hat{L}_5^c \hat{H}_u \hat{E}_5 + Y_{\nu 5} \hat{L}_5^c \hat{H}_d \hat{N}_5 \\ &\quad + Y_\nu \hat{L} \hat{H}_u \hat{N}^c + \lambda_{N^c} \hat{N}^c \hat{N}^c \hat{\varphi}_L + \mu_L \hat{\Phi}_L \hat{\varphi}_L, \\ \mathcal{W}_X &= \lambda_1 \hat{Q} \hat{Q}_5^c \hat{X} + \lambda_2 \hat{U}^c \hat{U}_5 \hat{X}' + \lambda_3 \hat{D}^c \hat{D}_5 \hat{X}' + \mu_X \hat{X} \hat{X}', \end{aligned} \quad (3)$$

with \mathcal{W}_{MSSM} representing the superpotential of the MSSM. The soft breaking terms \mathcal{L}_{soft} of the BLMSSM are collected here[11, 12].

$$\begin{aligned} \mathcal{L}_{soft} &= \mathcal{L}_{soft}^{MSSM} - (m_{\tilde{N}^c}^2)_{IJ} \tilde{N}_I^{c*} \tilde{N}_J^c - m_{\tilde{Q}_4}^2 \tilde{Q}_4^\dagger \tilde{Q}_4 - m_{\tilde{U}_4}^2 \tilde{U}_4^{c*} \tilde{U}_4^c - m_{\tilde{D}_4}^2 \tilde{D}_4^{c*} \tilde{D}_4^c \\ &\quad - m_{\tilde{Q}_5}^2 \tilde{Q}_5^{c\dagger} \tilde{Q}_5^c - m_{\tilde{U}_5}^2 \tilde{U}_5^{*} \tilde{U}_5 - m_{\tilde{D}_5}^2 \tilde{D}_5^{*} \tilde{D}_5 - m_{\tilde{L}_4}^2 \tilde{L}_4^\dagger \tilde{L}_4 - m_{\tilde{\nu}_4}^2 \tilde{N}_4^{c*} \tilde{N}_4^c \\ &\quad - m_{\tilde{e}_4}^2 \tilde{E}_4^{c*} \tilde{E}_4^c - m_{\tilde{L}_5}^2 \tilde{L}_5^{c\dagger} \tilde{L}_5^c - m_{\tilde{\nu}_5}^2 \tilde{N}_5^{*} \tilde{N}_5 - m_{\tilde{e}_5}^2 \tilde{E}_5^{*} \tilde{E}_5 - m_{\Phi_B}^2 \Phi_B^* \Phi_B \\ &\quad - m_{\varphi_B}^2 \varphi_B^* \varphi_B - m_{\Phi_L}^2 \Phi_L^* \Phi_L - m_{\varphi_L}^2 \varphi_L^* \varphi_L - (m_B \lambda_B \lambda_B + m_L \lambda_L \lambda_L + h.c.) \\ &\quad + \{ A_{u4} Y_{u4} \tilde{Q}_4 H_u \tilde{U}_4^c + A_{d4} Y_{d4} \tilde{Q}_4 H_d \tilde{D}_4^c + A_{u5} Y_{u5} \tilde{Q}_5^c H_d \tilde{U}_5 + A_{d5} Y_{d5} \tilde{Q}_5^c H_u \tilde{D}_5 \\ &\quad + A_{BQ} \lambda_Q \tilde{Q}_4 \tilde{Q}_5^c \Phi_B + A_{BU} \lambda_U \tilde{U}_4^c \tilde{U}_5 \varphi_B + A_{BD} \lambda_D \tilde{D}_4^c \tilde{D}_5 \varphi_B + B_B \mu_B \Phi_B \varphi_B + h.c. \} \\ &\quad + \{ A_{e4} Y_{e4} \tilde{L}_4 H_d \tilde{E}_4^c + A_{\nu 4} Y_{\nu 4} \tilde{L}_4 H_u \tilde{N}_4^c + A_{e5} Y_{e5} \tilde{L}_5^c H_u \tilde{E}_5 + A_{\nu 5} Y_{\nu 5} \tilde{L}_5^c H_d \tilde{N}_5 \\ &\quad + A_N Y_\nu \tilde{L} H_u \tilde{N}^c + A_{N^c} \lambda_{N^c} \tilde{N}^c \tilde{N}^c \varphi_L + B_L \mu_L \Phi_L \varphi_L + h.c. \} \\ &\quad + \{ A_1 \lambda_1 \tilde{Q} \tilde{Q}_5^c X + A_2 \lambda_2 \tilde{U}^c \tilde{U}_5 X' + A_3 \lambda_3 \tilde{D}^c \tilde{D}_5 X' + B_X \mu_X X X' + h.c. \}. \end{aligned} \quad (4)$$

$\mathcal{L}_{soft}^{MSSM}$ are the soft breaking terms of MSSM.

A. mass matrix

From the soft breaking terms and the scalar potential, we deduce the mass squared matrix for superfields X.

$$-\mathcal{L}_X = \begin{pmatrix} X^* & X' \end{pmatrix} \begin{pmatrix} |\mu_X|^2 + S_X & -\mu_X^* B_X^* \\ -\mu_X B_X & |\mu_X|^2 - S_X \end{pmatrix} \begin{pmatrix} X \\ X'^* \end{pmatrix},$$

$$S_X = \frac{g_B^2}{2} \left(\frac{2}{3} + B_4 \right) (v_B^2 - \bar{v}_B^2). \quad (5)$$

We diagonalize the mass squared matrix for the superfields X through the unitary transformation,

$$\begin{pmatrix} X_1 \\ X_2 \end{pmatrix} = Z_X^\dagger \begin{pmatrix} X \\ X'^* \end{pmatrix}, \quad Z_X^\dagger \begin{pmatrix} |\mu_X|^2 + S_X & -\mu_X^* B_X^* \\ -\mu_X B_X & |\mu_X|^2 - S_X \end{pmatrix} Z_X = \begin{pmatrix} m_{X_1}^2 & 0 \\ 0 & m_{X_2}^2 \end{pmatrix}. \quad (6)$$

ψ_X and $\psi_{X'}$ are the superpartners of the scalar superfields X and X' . ψ_X and $\psi_{X'}$ can composite four-component Dirac spinors, whose mass term are given out[14]

$$-\mathcal{L}_{\tilde{X}}^{mass} = \mu_X \tilde{X} \tilde{X}, \quad \tilde{X} = \begin{pmatrix} \psi_X \\ \bar{\psi}_{X'} \end{pmatrix}, \quad (7)$$

with μ_X denoting the mass of \tilde{X} .

In the BLMSSM, there are the new baryon boson, the $SU(2)_L$ singlets Φ_B and φ_B . Their superpartners are respectively λ_B , ψ_{Φ_B} and ψ_{φ_B} , and they mix together producing 3 baryon neutralinos. In the base $(i\lambda_B, \psi_{\Phi_B}, \psi_{\varphi_B})$, the mass mixing matrix M_{BN} is obtained and diagonalized by the rotation matrix Z_{NB} [20].

$$M_{BN} = \begin{pmatrix} 2m_B & -v_B g_B & \bar{v}_B g_B \\ -v_B g_B & 0 & -\mu_B \\ \bar{v}_B g_B & -\mu_B & 0 \end{pmatrix}, \quad \chi_{B_i}^0 = \begin{pmatrix} k_{B_i}^0 \\ \bar{k}_{B_i}^0 \end{pmatrix},$$

$$i\lambda_B = Z_{NB}^{1i} k_{B_i}^0, \quad \psi_{\Phi_B} = Z_{NB}^{2i} k_{B_i}^0, \quad \psi_{\varphi_B} = Z_{NB}^{3i} k_{B_i}^0. \quad (8)$$

$\chi_{B_i}^0 (i = 1, 2, 3)$ represent the mass eigenstates of baryon neutralinos.

The exotic quarks with charged 2/3 is in four-component Dirac spinors, whose mass matrix reads as[12]

$$-\mathcal{L}_{t'}^{mass} = (\bar{t}_{4R} \quad \bar{t}_{5R}) \begin{pmatrix} \frac{1}{\sqrt{2}}\lambda_Q v_B & -\frac{1}{\sqrt{2}}Y_{u5}v_d \\ -\frac{1}{\sqrt{2}}Y_{u4}v_u & \frac{1}{\sqrt{2}}\lambda_u \bar{v}_B \end{pmatrix} \begin{pmatrix} t'_{4L} \\ t'_{5L} \end{pmatrix}, \quad (9)$$

Using the unitary transformations, the two mass eigenstates of exotic quarks with charged 2/3 are obtained by the rotation matrices U_t and W_t ,

$$\begin{pmatrix} t_{4L} \\ t_{5L} \end{pmatrix} = U_t^\dagger \begin{pmatrix} t'_{4L} \\ t'_{5L} \end{pmatrix}, \quad \begin{pmatrix} t_{4R} \\ t_{5R} \end{pmatrix} = W_t^\dagger \begin{pmatrix} t'_{4R} \\ t'_{5R} \end{pmatrix},$$

$$W_t^\dagger \begin{pmatrix} \frac{1}{\sqrt{2}}\lambda_Q v_B & -\frac{1}{\sqrt{2}}Y_{u5}v_d \\ -\frac{1}{\sqrt{2}}Y_{u4}v_u & \frac{1}{\sqrt{2}}\lambda_u \bar{v}_B \end{pmatrix} U_t = \text{diag}(m_{t_4}, m_{t_5}). \quad (10)$$

The mass squared matrix for charged 2/3 exotic squarks $\mathcal{M}_{\tilde{t}'}^2$ is obtained in our previous work[12]. For saving space in the work, we do not show it here. $\mathcal{M}_{\tilde{t}'}^2$ is diagonalized by $Z_{\tilde{t}'}$ through the formula $Z_{\tilde{t}'}^\dagger \mathcal{M}_{\tilde{t}'}^2 Z_{\tilde{t}'} = \text{diag}(m_{\tilde{u}_1}^2, m_{\tilde{u}_2}^2, m_{\tilde{u}_3}^2, m_{\tilde{u}_4}^2)$.

B. needed couplings

To study quark EDMs, the couplings between photon (gluon) and exotic quarks(exotic squarks) are necessary. We derive the couplings between photon (gluon) and exotic quarks.

$$\mathcal{L}_{\gamma(g)q'q'} = -\frac{2e}{3} \sum_{i=1}^2 \bar{t}_{i+3} \gamma^\mu t_{i+3} F_\mu - g_3 \sum_{i=1}^2 \bar{t}_{i+3} T^a \gamma^\mu t_{i+3} G_\mu^a, \quad (11)$$

with F_μ and G_μ^a representing electromagnetic field and gluon field respectively. T^a ($a = 1, \dots, 8$) are the strong $SU(3)$ gauge group generators. Similarly, the couplings between photon (gluon) and exotic squarks are also deduced

$$\mathcal{L}_{\gamma(g)\tilde{q}'\tilde{q}'} = -\frac{2}{3}e \sum_{j,\beta=1}^4 \delta_{j\beta} F_\mu \tilde{\mathcal{U}}_j^* i \tilde{\partial}^\mu \tilde{\mathcal{U}}_\beta - g_3 T^a \sum_{j,\beta=1}^4 \delta_{j\beta} G_\mu^a \tilde{\mathcal{U}}_j^* i \tilde{\partial}^\mu \tilde{\mathcal{U}}_\beta. \quad (12)$$

From the superpotential W_X , one can find there are interactions at tree level for quark, exotic quark and X. The needed Yukawa interactions can be deduced from the superpotential W_X . The couplings of quark-exotic quark-X are shown in the mass basis,

$$\mathcal{L}_{Xt'u} = \sum_{i,j=1}^2 \left((\mathcal{N}_{t'}^L)_{ij} X_j \bar{t}_{i+3} P_L u^I + (\mathcal{N}_{t'}^R)_{ij} X_j \bar{t}_{i+3} P_R u^I \right) + h.c.$$

$$(\mathcal{N}_{t'}^L)_{ij} = -\lambda_1 (W_t^\dagger)_{i1} (Z_X)_{1j}, \quad (\mathcal{N}_{t'}^R)_{ij} = -\lambda_2^* (U_t^\dagger)_{i2} (Z_X)_{2j}. \quad (13)$$

From the superpotential W_X , in the same way we can also obtain another type Yukawa couplings (quark-exotic squark- \tilde{X})[14].

$$\mathcal{L}_{\bar{u}\tilde{X}\tilde{U}} = - \sum_{i=1}^4 \bar{u} \left(\lambda_1 (Z_{\tilde{U}}^*)_{3i} P_L + \lambda_2 (Z_{\tilde{U}})_{4i} P_R \right) \tilde{X} \tilde{U}_i. \quad (14)$$

Beyond the MSSM, there are couplings for baryon neutralino, quarks and squarks. They are deduced in our previous work[20], and can give new contributions to the quark EDMs.

$$\mathcal{L}(\chi_B^0 q \tilde{q}) = \sum_{I,i=1}^3 \sum_{j=1}^6 \frac{\sqrt{2}}{3} g_B \bar{\chi}_{B_i^0} (Z_{N_B}^{1i} Z_{\tilde{U}}^{Ij*} P_L - Z_{N_B}^{1i*} Z_{\tilde{U}}^{(I+3)j*} P_R) u^I \tilde{U}_j^* + H.c. \quad (15)$$

III. FORMULATION

Using the effective Lagrangian[21] method, one obtains the fermion EDM d_f from

$$\mathcal{L}_{EDM} = -\frac{i}{2} d_f \bar{f} \sigma^{\mu\nu} \gamma_5 f F_{\mu\nu}, \quad (16)$$

with $F_{\mu\nu}$ representing the electromagnetic field strength, f denoting a fermion field. It is obviously that this effective Lagrangian is CP-violating. In the fundamental interactions, this CP-violating Lagrangian can not be obtained at tree level. Considering the CP-violating electroweak theory, one can get this effective Lagrangian from the loop diagrams. The chromoelectric dipole moment (CEDM) $\bar{f} T^a \sigma^{\mu\nu} \gamma_5 f G_{\mu\nu}^a$ of quark can also give contribution to the quark EDM. $G_{\mu\nu}^a$ denotes the gluon field strength.

To describe the CP-violating operators obtained from loop diagrams, the effective method is convenient. The coefficients of the quark EDM and CEDM at the matching scale μ should be evolved down to the quark mass scale with the renormalization group equations. At matching scale, we can obtain the effective Lagrangian with the CP-violating operators. The effective Lagrangian containing operators relating with the quark EDM and CEDM are

$$\begin{aligned} \mathcal{L}_{eff} &= \sum_i^4 C_i(\Lambda) \mathcal{O}_i(\Lambda), \\ \mathcal{O}_1 &= \bar{q} \sigma^{\mu\nu} P_L q F_{\mu\nu}, & \mathcal{O}_2 &= \bar{q} \sigma^{\mu\nu} P_R q F_{\mu\nu}, \\ \mathcal{O}_3 &= \bar{q} T^a \sigma^{\mu\nu} P_L q G_{\mu\nu}^a, & \mathcal{O}_4 &= \bar{q} T^a \sigma^{\mu\nu} P_R q G_{\mu\nu}^a. \end{aligned} \quad (17)$$

with Λ representing the energy scale, where the Wilson coefficients $C_i(\Lambda)$ are evaluated.

In our previous work[14], we have studied the neutron EDM in the CP-violating BLMSSM, where the contributions from baryon neutralino-squark and \tilde{X} -exotic squark are

neglected, because they are all small in the used parameter space. Here we take into account all the contributions at one loop level to study the c and t EDMs. In the CP-violating BLSSM, the one-loop corrections to the quark EDMs and CEDMs can be divided into six types according to the quark self-energy diagrams. We divide the quark self-energy diagrams according to the virtual particles as: 1 gluino-squark, 2 neutralino-squark, 3 chargino-squark, 4 X -exotic quark, 5 baryon neutralino-squark, 6 \tilde{X} -exotic squark.

From the quark selfenergy diagrams, one obtains the needed triangle diagrams by attaching a photon or gluon on the internal lines in all possible ways. After the calculation, we obtain the effective Lagrangian contributing to the quark EDMs and CEDMs. The BLSSM is larger than MSSM and includes the MSSM contributions. In Fig.(6), we plot all the one loop self energy diagrams of the up-type quark.

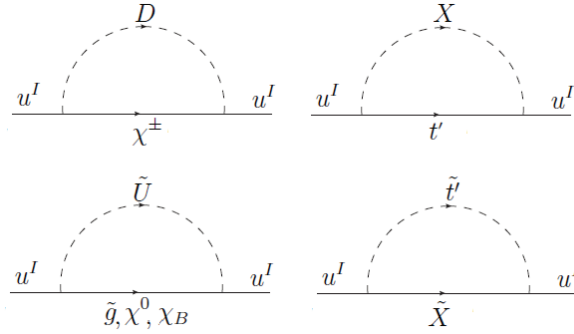


FIG. 1: In the BLSSM, one loop self energy diagrams are collected here, and the corresponding triangle diagrams are obtained from them by attaching a photon or a gluon in all possible ways.

In this section, we show the one loop corrections to the quark EDMs (CEDMs). The one loop chargino-squark contributions are

$$\begin{aligned}
d_{\chi_k^\pm}^\gamma(u^I) &= \frac{e\alpha}{4\pi s_W^2} V_{UD}^\dagger V_{DU} \sum_i^6 \sum_k^2 \mathbf{Im} \left((A_C^D)_{k,i} (B_C^D)_{i,k}^\dagger \right) \frac{m_{\chi_k^\pm}}{m_{\tilde{D}_i}^2} \\
&\quad \times \left[-\frac{1}{3} \mathcal{B} \left(\frac{m_{\chi_k^\pm}^2}{m_{\tilde{D}_i}^2} \right) + \mathcal{A} \left(\frac{m_{\chi_k^\pm}^2}{m_{\tilde{D}_i}^2} \right) \right], \\
d_{\chi_k^\pm}^g(u^I) &= \frac{g_3\alpha}{4\pi s_W^2} V_{UD}^\dagger V_{DU} \sum_i^6 \sum_k^2 \mathbf{Im} \left((A_C^D)_{k,i} (B_C^D)_{i,k}^\dagger \right) \frac{m_{\chi_k^\pm}}{m_{\tilde{D}_i}^2} \mathcal{B} \left(\frac{m_{\chi_k^\pm}^2}{m_{\tilde{D}_i}^2} \right), \\
(A_C^D)_{k,i} &= \frac{m_{u^I}}{\sqrt{2}m_W s_\beta} (Z_{\tilde{D}})^{Ji} (Z_+)^{2k}, \\
(B_C^D)_{k,i} &= \frac{m_{d^I}}{\sqrt{2}m_W c_\beta} (Z_{\tilde{D}})^{(J+3)i} (Z_-)^{2k} - (Z_{\tilde{D}})^{Ji} (Z_-)^{1k}.
\end{aligned} \tag{18}$$

Here $\alpha = e^2/(4\pi)$, $s_W = \sin \theta_W$, $c_W = \cos \theta_W$, θ_W is the Weinberg angle, V is the CKM matrix. We define the one loop functions $\mathcal{A}(r)$ and $\mathcal{B}(r)$ as[9]

$$\begin{aligned}
\mathcal{A}(r) &= [2(1-r)^2]^{-1} [3-r+2\ln r/(1-r)], \\
\mathcal{B}(r) &= [2(r-1)^2]^{-1} [1+r+2r\ln r/(1-r)].
\end{aligned} \tag{19}$$

$m_{\tilde{D}_i}$ ($i = 1 \dots 6$) are the squarks masses and $m_{\chi_k^0}$ ($k = 1, 2, 3, 4$) denote the eigenvalues of neutralino mass matrix. $Z_{\tilde{D}_i}$ is the rotation matrix to diagonalize the mass squared matrix for the down type squark. Z_- and Z_+ are the rotation matrices to obtain the mass eigenstates of charginos.

We show the gluino-squark corrections to the quark EDMs and CEDMs

$$\begin{aligned} d_g^\gamma(u^I) &= -\frac{4}{9\pi} e\alpha_s \sum_{i=1}^6 \mathbf{Im} \left((\mathcal{Z}_{\tilde{U}})^{(I+3)i} (\mathcal{Z}_{\tilde{U}})^{Ii*} e^{-i\theta_3} \right) \frac{|m_{\tilde{g}}|}{m_{\tilde{U}_i}^2} \mathcal{B} \left(\frac{|m_{\tilde{g}}|^2}{m_{\tilde{U}_i}^2} \right), \\ d_g^g(u^I) &= \frac{g_3\alpha_s}{4\pi} \sum_{i=1}^6 \mathbf{Im} \left((\mathcal{Z}_{\tilde{U}})^{(I+3)i} (\mathcal{Z}_{\tilde{U}})^{Ii*} e^{-i\theta_3} \right) \frac{|m_{\tilde{g}}|}{m_{\tilde{U}_i}^2} \mathcal{C} \left(\frac{|m_{\tilde{g}}|^2}{m_{\tilde{U}_i}^2} \right), \end{aligned} \quad (20)$$

with $\alpha_s = g_3^2/(4\pi)$. $\mathcal{Z}_{\tilde{U}}$ is the matrix for the up type squarks, with the definition $\mathcal{Z}_{\tilde{U}}^\dagger \mathbf{m}_{\tilde{U}}^2 \mathcal{Z}_{\tilde{U}} = \text{diag}(m_{\tilde{q}_1}^2, \dots, m_{\tilde{q}_6}^2)$. The concrete form of the loop function $\mathcal{C}(r)$ is[9]

$$\mathcal{C}(r) = [6(r-1)^2]^{-1} [10r - 26 - (2r-18) \ln r / (r-1)]. \quad (21)$$

To check the functions $\mathcal{A}(r)$, $\mathcal{B}(r)$ and $\mathcal{C}(r)$ in the Ref.[9], we calculate the one loop triangle diagrams using the effective Lagrangian method. In the calculation, we use the approximation

$$\frac{1}{(k+p)^2 - m^2} = 1 - \frac{2k \cdot p + p^2}{k^2 - m^2} + \frac{4(k \cdot p)^2}{(k^2 - m^2)^2}, \quad (22)$$

with k representing the loop integral momentum and p representing the external momentum. It is reasonable because the internal particles are at the order of TeV, and the external quark is lighter than TeV, even for t quark. The ratio $\frac{m_t^2}{1\text{TeV}^2} \sim 0.03$ is small enough to use the approximation formula.

For the diagram that the photon is just attached on the internal charged Fermions, our result corresponding to $\mathcal{A}(r)$ is the function $a[F, S]$

$$\begin{aligned} a[F, S] &= \frac{\Lambda_{NP}^2}{i\pi^2} \int dk^4 \frac{k^2}{(k^2 - m_F^2)^3 (k^2 - m_S^2)} \\ &= -\frac{F^2 + 2S^2 \log(F) - 4FS + 3S^2 - 2S^2 \log(S)}{2(F-S)^3}, \end{aligned} \quad (23)$$

with the definition $F = \frac{m_F^2}{\Lambda_{NP}^2}$ and $S = \frac{m_S^2}{\Lambda_{NP}^2}$. Λ_{NP} represents the the energy scale of the new physics. In order to compare with the function $\mathcal{A}(r)$, we use $\lambda_{NP}^2 = m_S^2$, $S \rightarrow 1$, $F \rightarrow \frac{m_F^2}{m_S^2} = r$ and obtain

$$a[r, 1] = -\frac{r^2 - 4r + 2 \log(r) + 3}{2(r-1)^3} = \mathcal{A}(r). \quad (24)$$

When the photon is just emitted from the internal charged scalars, our result for $\mathcal{B}(r)$ is

$$\begin{aligned} b[F, S] &= \frac{\Lambda_{NP}^2}{i\pi^2} \int dk^4 \frac{m_S^2}{(k^2 - m_F^2)(k^2 - m_S^2)^3} \\ &= \frac{F^2 - 2FS \log(F) + 2FS \log(S) - S^2}{2(F-S)^3}, \end{aligned} \quad (25)$$

With the same approach as that of $a[F, S]$, $b[F, S]$ turns into the form

$$b[r, 1] = \frac{r^2 - 2r \log(r) - 1}{2(r-1)^3} = \mathcal{B}(r). \quad (26)$$

$\mathcal{C}(r)$ is obtained from the diagrams that the photon is attached on both the internal charged Fermions and charged scalars. Therefore, $\mathcal{C}(r)$ is the linear combination of $\mathcal{A}(r)$ and $\mathcal{B}(r)$,

$$\mathcal{C}(r) = \frac{1}{3}\mathcal{B}(r) - 3\mathcal{A}(r). \quad (27)$$

From the above discussion, the results in Ref.[9] are the same with our results. In our calculation, we do not ignore the mass of the external fermion. So, it is clear that the analytical expressions for the quark EDM in this work are practicable for both c and t.

Similarly, the contributions from the one loop neutralino-squark diagrams are also obtained

$$\begin{aligned} d_{\chi_k^0}^\gamma(u^I) &= \frac{e\alpha}{12\pi s_W^2 c_W^2} \sum_{i=1}^6 \sum_{k=1}^4 \mathbf{Im}\left((A_N)_{k,i}(B_N)_{i,k}^\dagger\right) \frac{m_{\chi_k^0}}{m_{\tilde{U}_i}^2} \mathcal{B}\left(\frac{m_{\chi_k^0}^2}{m_{\tilde{U}_i}^2}\right), \\ d_{\chi_k^0}^g(u^I) &= \frac{g_3\alpha}{8\pi s_W^2 c_W^2} \sum_{i=1}^6 \sum_{k=1}^4 \mathbf{Im}\left((A_N)_{k,i}(B_N)_{i,k}^\dagger\right) \frac{m_{\chi_k^0}}{m_{\tilde{U}_i}^2} \mathcal{B}\left(\frac{m_{\chi_k^0}^2}{m_{\tilde{U}_i}^2}\right), \\ (A_N)_{k,i} &= -\frac{4}{3}s_W(Z_{\tilde{U}})^{(I+3)i}(Z_N)^{1k} + \frac{m_{u^I}c_W}{m_W s_\beta}(Z_{\tilde{U}})^{Ii}(Z_N)^{4k}, \\ (B_N)_{k,i} &= (Z_{\tilde{U}})^{Ii}\left(\frac{s_W}{3}(Z_N)^{1k*} + c_W(Z_N)^{2k*}\right) + \frac{m_{u^I}c_W}{m_W s_\beta}(Z_{\tilde{U}})^{(I+3)i}(Z_N)^{4k*}. \end{aligned} \quad (28)$$

Z_N is the mixing matrix to get the eigenvalues $m_{\chi_k^0}$ ($k = 1, 2, 3, 4$) of neutralino mass matrix. In the MSSM, there are also the front three type contributions Eqs.(18)(20)(28).

At one loop level, there are three new type corrections beyond MSSM. The corrections from the virtual X and exotic up-type quark has been deduced in the work[14]

$$\begin{aligned} d_{X_j}^\gamma(u^I) &= \frac{e\lambda_1\lambda_2}{24\pi^2} \sum_{i,j=1}^2 \frac{m_{t_{i+3}}}{m_{X_j}^2} \mathbf{Im}\left((W_t)_{1i}(Z_X)_{1j}^*(U_t)_{2i}^*(Z_X)_{2j}\right) \mathcal{A}\left(\frac{m_{t_{i+3}}^2}{m_{X_j}^2}\right), \\ d_{X_j}^g(u^I) &= \frac{g_3\lambda_1\lambda_2}{16\pi^2} \sum_{i,j=1}^2 \frac{m_{t_{i+3}}}{m_{X_j}^2} \mathbf{Im}\left((W_t)_{1i}(Z_X)_{1j}^*(U_t)_{2i}^*(Z_X)_{2j}\right) \mathcal{A}\left(\frac{m_{t_{i+3}}^2}{m_{X_j}^2}\right), \end{aligned} \quad (29)$$

$m_{t_{i+3}}$ and m_{X_i} ($i=1,2$) are mass eigenvalues of the exotic up type quarks and X superfields. W_t, U_t and Z_X are the mixing matrices defined in the Eqs.(6)(10).

The one loop baryon neutralino and up-type squark contributions read as

$$d_{\chi_B}^\gamma(u^I) = -\frac{eg_B^2}{108\pi^2} \sum_{i=1}^2 \sum_{j=1}^6 \mathbf{Im}\left((Z_{N_B}^{1i})^2 Z_{\tilde{U}}^{(I+3)j} Z_{\tilde{U}}^{Ij*}\right) \frac{m_{\chi_B^i}}{m_{\tilde{U}_j}^2} \mathcal{B}\left(\frac{m_{\chi_B^i}^2}{m_{\tilde{U}_j}^2}\right),$$

$$d_{\chi_B}^g(u^I) = -\frac{g_3 g_B^2}{72\pi^2} \sum_{i=1}^2 \sum_{j=1}^6 \mathbf{Im} \left((Z_{NB}^{1i})^2 Z_{\tilde{U}}^{(I+3)j} Z_{\tilde{U}}^{Ij*} \right) \frac{m_{\chi_B^i}}{m_{\tilde{U}_j}^2} \mathcal{B} \left(\frac{m_{\chi_B^i}^2}{m_{\tilde{U}_j}^2} \right). \quad (30)$$

$m_{\chi_B^i}$ ($i=1,2,3$) are the eigenvalues of baryon neutralino masses.

The exotic up-type squark and \tilde{X} can also contribute to the $c(t)$ EDM and CEDM

$$\begin{aligned} d_{\tilde{X}}^\gamma &= \frac{e\lambda_1\lambda_2}{24\pi^2} \sum_{i=1}^2 \mathbf{Im} \left((Z_{\tilde{t}'}^{3i*}) (Z_{\tilde{t}'}^{4i*}) \right) \frac{m_{\tilde{X}}}{m_{\tilde{t}_{i+3}}^2} \mathcal{B} \left(\frac{m_{\tilde{X}}^2}{m_{\tilde{t}_{i+3}}^2} \right), \\ d_{\tilde{X}}^g &= \frac{g_3\lambda_1\lambda_2}{16\pi^2} \sum_{i=1}^2 \mathbf{Im} \left((Z_{\tilde{t}'}^{3i*}) (Z_{\tilde{t}'}^{4i*}) \right) \frac{m_{\tilde{X}}}{m_{\tilde{t}_{i+3}}^2} \mathcal{B} \left(\frac{m_{\tilde{X}}^2}{m_{\tilde{t}_{i+3}}^2} \right), \end{aligned} \quad (31)$$

with $m_{\tilde{X}}$ and $m_{\tilde{t}_{i+3}}$ denoting the masses of \tilde{X} and exotic up-type squark respectively.

Using the renormalization group equations[22], we evolve the coefficients of the quark EDM and CEDM at matching scale μ down to the quark(c , t) mass scale[23]

$$d_q^\gamma(\Lambda_\chi) = 1.53 d_q^\gamma(\Lambda), \quad d_q^g(\Lambda_\chi) = 3.4 d_q^g(\Lambda), \quad (32)$$

The quark CEDMs can contribute to the quark EDMs at low energy scale. Therefore, they must be taken into account in the numerical calculation and the formula is[24]

$$d_c = d_c^\gamma + \frac{e}{4\pi} d_c^g. \quad (33)$$

IV. THE NUMERICAL RESULTS

Here, the results are studied numerically. We take into account not only the experiment constraints from Higgs and neutrino, but also our previous works in this model. From ATLAS collaboration, $m_{\tilde{g}} \geq 1460$ GeV is the updated bound on the gluino mass[25]. The parameters are supposed as

$$\begin{aligned} m_1 = m_2 = A_{BQ} = A_{BU} = 1 \text{ TeV}, \quad B_X = 500 \text{ GeV}, \quad m_D^2 = \delta_{ij} \text{ TeV}^2, \quad (i, j = 1, 2, 3), \\ A_u = A_d = A'_u = A'_d = 500 \text{ GeV}, \quad Y_{d_4} = Y_{d_5} = 0.7 Y_b, \quad \lambda_Q = \lambda_u = 0.5, \\ m_{\tilde{Q}_4}^2 = m_{\tilde{Q}_5}^2 = m_{\tilde{U}_4}^2 = m_{\tilde{U}_5}^2 = 1 \text{ TeV}^2, \quad B_4 = \frac{3}{2}, \quad A_{u_4} = A_{u_5} = 500 \text{ GeV}. \end{aligned} \quad (34)$$

A. c quark EDM

For the c quark EDM, we use the following parameters as

$$\begin{aligned} \tan \beta = 10, \quad \mu = 800 \text{ GeV}, \quad m_{\tilde{g}} = 1600 \text{ GeV}, \\ \tan \beta_B = 2, \quad v_{B_t} = 3 \text{ TeV}, \quad Y_{u_4} = Y_{u_5} = 0.7 Y_t. \end{aligned} \quad (35)$$

The baryon neutralino and squarks can give contributions to c quark EDM, which is relevant to the parameters g_B and m_B . m_B representing baryon gaugino masses, can have nonzero CP-violating phase θ_{m_B} . Both m_B and g_B influence the baryon neutralino masses. Furthermore, g_B is the coupling constant for the quark-squark-baryon neutralino. So, with $\theta_{m_B} = -0.5\pi$, $\lambda_1 = \lambda_2 = 0.1$, $\mu_X = \mu_B = 3 \text{ TeV}$, $m_Q^2 = m_U^2 = \delta_{ij}\text{TeV}^2$ for $(i, j = 1, 2, 3)$, we study c quark EDM versus g_B . If we do not mention the other CP-violating phases, it indicates the other CP-violating phases are zero. In Fig.2, the numerical results corresponding to $m_B = (1, 2, 3) \times e^{i\theta_{m_B}}\text{TeV}$ are plotted by the solid line, dotted line and dashed line respectively. In the whole, the three lines are all increasing functions of g_B . The dotted line and the dashed line vary slightly. The solid line largen quickly with the increasing g_B . These three lines also imply the results are suppressed by large $|m_B|$. The obtained numerical results from the nonzero CP-violating phase θ_{m_B} are at the order of $10^{-21}e.cm$, which are four orders smaller than the upper bound of c quark EDM.

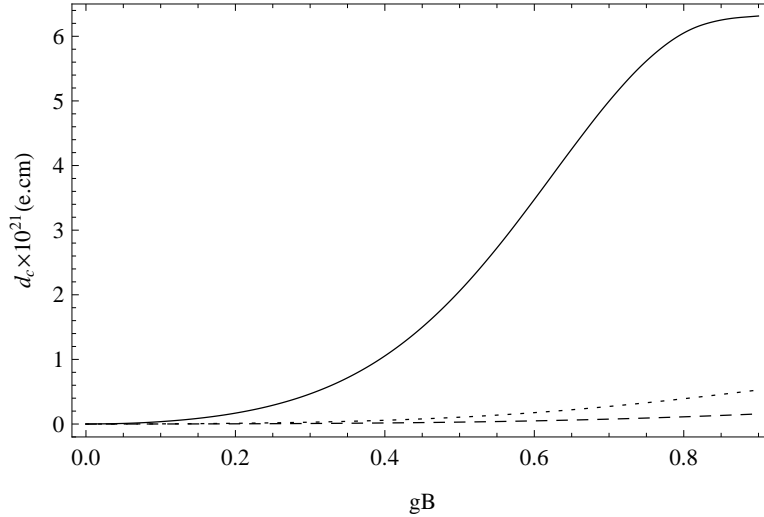


FIG. 2: The one loop corrections to c EDM versus g_B with $\theta_{m_B} = -0.5\pi$, the solid line, dotted line and dashed line corresponding to $m_B = (1, 2, 3) \times e^{i\theta_{m_B}}\text{TeV}$ respectively.

Here, we discuss the effects from the new phase θ_{μ_B} of μ_B , it can influence the baryon neutralino masses. Based on the supposition $\mu_B = 2 \times e^{i\theta_{\mu_B}} \text{ TeV}$ ($\theta_{\mu_B} = 0.5\pi$), $\lambda_1 = \lambda_2 = 0.5$, $\mu_X = 3 \text{ TeV}$, $m_Q^2 = 4\delta_{ij} \text{ TeV}^2$, $m_U^2 = 2\delta_{ij} \text{ TeV}^2$ ($i, j = 1, 2, 3$), the results versus m_B are shown as the solid line for $g_B = \frac{1}{3}$. The solid line decreases quickly in the region $1000\text{GeV} < m_B < 1300\text{GeV}$. When $m_B > 1300\text{GeV}$, the change extent of the solid line is small. The dotted line and the dashed line respectively represent the results for $g_B = \frac{1}{5}$ and

$g_B = \frac{1}{10}$, and they are both the slowly decreasing functions of m_B . Generally speaking, the results are around $10^{-21}e.cm$ that are at the same order of Fig.2.

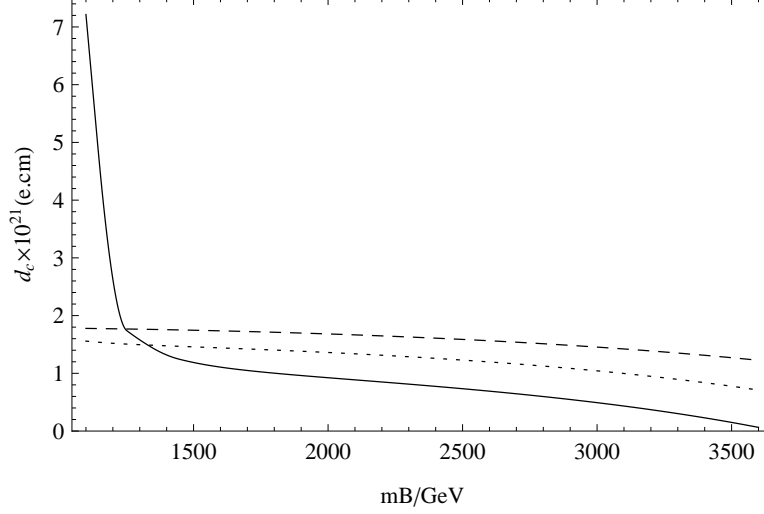


FIG. 3: The one loop corrections to c EDM versus m_B with $\theta_{\mu_B} = 0.5\pi$, the solid line, dotted line and dashed line corresponding to $g_B = (1/3, 1/5, 1/10)$ respectively.

λ_1 and λ_2 are important parameters for the couplings: quark-exotic quark-X and quark-exotic squark- \tilde{X} . Therefore, the numerical results maybe be influenced obviously by the varying λ_1 and λ_2 . For simplicity, we suppose $\lambda_1 = \lambda_2 = Lam$, $g_B = \frac{1}{3}$, $m_B = 1\text{TeV}$, $\mu_B = 3\text{TeV}$, $m_Q^2 = m_U^2 = \delta_{ij}\text{TeV}^2$ for $(i, j = 1, 2, 3)$. With the nonzero CP-violating phase $\theta_X = (0.5\pi, 0.3\pi, 0.1\pi)$ and $\mu_X = e^{i\theta_X} \text{TeV}$, the results versus Lam are denoted respectively by the solid line, dotted line and dashed line. The three lines are the increasing functions of Lam and the results are around $10^{-17}e.cm$. As $Lam > 0.8$, the solid line even exceeds its the upper bound $5.0 \times 10^{-17}e.cm$. From the Figs.(2, 3, 4), one can find the effects from θ_X are much larger than the effects from θ_{μ_B} and θ_{m_B} .

B. t quark EDM

To calculate the t quark EDM numerically, we use the parameters as

$$g_B = \frac{1}{3}, m_B = 1 \text{ TeV}, \mu_B = 3 \text{ TeV}. \quad (36)$$

The quark-gluino-squark coupling corrections to t quark EDM are shown in Eq.(20). $\tan \beta$ is important, because it influences the masses of chargino, neutralino, squark and so on.

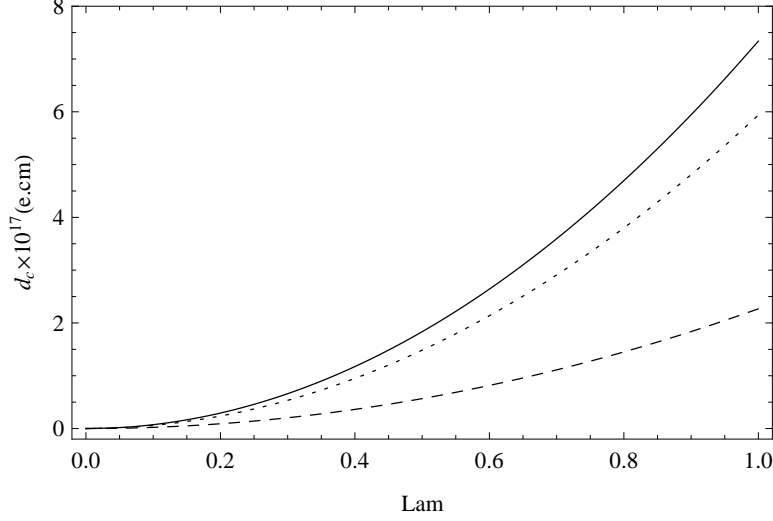


FIG. 4: The one loop corrections to c EDM versus Lam, while the solid line, dotted line and dashed line denoting the results with $\mu_X = e^{i(0.5\pi, 0.3\pi, 0.1\pi)}$ TeV respectively.

The mixing matrices of squarks and exotic squarks have relation with $\tan\beta$. The absolute value of gluino mass also influence the results obviously from Eq.(20). Using the parameters $\theta_3 = -0.5\pi$, $\mu = 800$ GeV, $\tan\beta_B = 2$, $Y_{u_4} = Y_{u_5} = 0.7Y_t$, $\lambda_1 = \lambda_2 = 0.5$, $\mu_X = 1$ TeV, $V_{B_t} = 3300$ GeV, $m_Q^2 = \delta_{ij}1500^2\text{GeV}^2$, $m_U^2 = \delta_{ij}\text{TeV}^2$ with $(i, j = 1, 2, 3)$, for t quark EDM we plot the results versus $m_{\tilde{g}}$. In Fig.(5), the solid line ($\tan\beta = 5$), dotted line ($\tan\beta = 10$) and dashed line ($\tan\beta = 15$) are all decreasing functions of $m_{\tilde{g}}$. During the $m_{\tilde{g}}$ region (1500 ~ 2000) GeV, the results of the three lines shrink quickly. Near the point $m_{\tilde{g}} = 1480$ GeV, the theoretical predictions are at the order of $10^{-16}e.cm$ and even reach $10^{-15}e.cm$. On the other hand, the extent of the influence from $\tan\beta$ is not large.

The effects to the t quark EDM from the μ parameter are also of interest. μ is included in the mass matrices of chargino and neutralino. On the other hand m_Q^2 and m_u^2 can affect the masses and mixings of the up-type squark. For simplification of the numerical discussion, we adopt the relation $m_Q^2 = m_U^2 = Mus^2$ and use the parameters $\tan\beta = 10$, $m_{\tilde{g}} = 1600$ GeV, $\tan\beta_B = 1.5$, $V_{B_t} = 3600$ GeV, $Y_{u_4} = Y_{u_5} = 0.7Y_t$, $\lambda_1 = \lambda_2 = 0.1$, $\mu_X = 1$ TeV. As $\theta_\mu = -0.5\pi$ and $\mu = (1500, 2500, 3500)e^{i\theta_\mu}$ GeV, the numerical results for t quark EDM are plotted respectively by the dotted line, solid line and dashed line. The results are all decreasing functions of Mus and at the order of $10^{-18}e.cm$ as $Mus < 3500$ GeV. The absolute value of μ also influences the results, and the extent is small.

The exotic squarks and exotic quarks are in connection with Y_{u_4} and Y_{u_5} , and the related

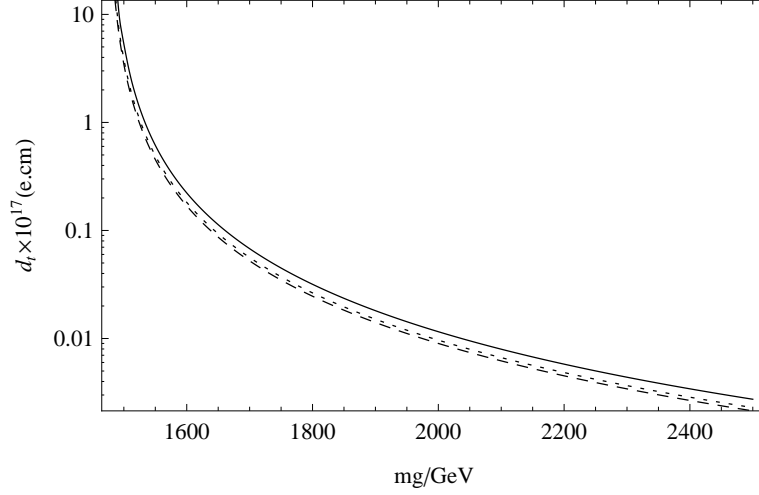


FIG. 5: The one loop corrections to t EDM versus $m_{\tilde{g}}$ with $\theta_3 = -0.5\pi$, the solid line, dotted line and dashed line corresponding to $\tan \beta = (5, 10, 15)$.

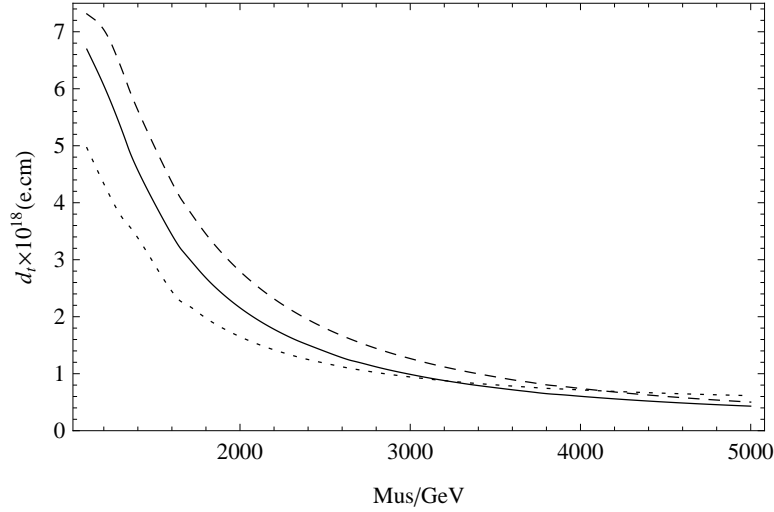


FIG. 6: The one loop corrections to t EDM versus μ_S with $\theta_\mu = -0.5\pi$, the dotted line, solid line and dashed line corresponding to the results with $\mu = (1500, 2500, 3500)e^{i\theta_\mu}$ GeV.

contributions are shown in Eqs.(29,31). As discussed in the front subsection, nonzero θ_X can give large contributions. In Fig.7 we plot the solid line, dotted line and dashed line versus $Yu45$ with $Y_{u4} = Y_{u5} = Yu45 * Yt$, $\theta_X = (0.5\pi, 0.2\pi, 0.05\pi)$ and $\mu_X = 1 e^{i\theta_X}$ TeV. The other used parameters are $\tan \beta = 10$, $\mu = 800\text{GeV}$, $m_{\tilde{g}} = 1600$ GeV, $\tan \beta_B = 2$, $V_{Bt} = 3$ TeV, $\lambda_1 = \lambda_2 = 0.5$, $m_Q^2 = m_U^2 = \delta_{ij}\text{TeV}^2$ with $(i, j = 1, 2, 3)$. They are all increasing functions of $Yu45$ and as $Yu45 > 0.8$ the numerical results largen quickly. At the point $Yu45 = 0.7$, the solid line and dotted line are larger than $1 \times 10^{-17}e.cm$. The three lines

are at the order of $10^{-18}e.cm$, when $Yu45$ is small. For c and t quark EDMs, in our used parameter space the CP-violating phases θ_3 and θ_X are important and can provide large contributions.

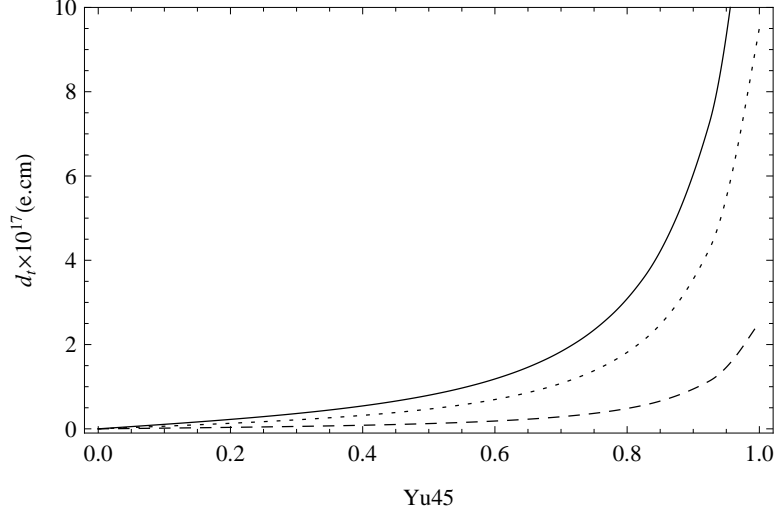


FIG. 7: The one loop corrections to t EDM versus $Yu45$ with $\mu_X = e^{i\theta_X}$ TeV, the solid line, dotted line and dashed line corresponding to the results with $\theta_X = (0.5\pi, 0.2\pi, 0.05\pi)$.

V. DISCUSSION

In the CP-violating BLMSSM, there are new CP-violating phases θ_X , θ_{μ_B} , θ_{m_B} beyond MSSM. For the c quark EDM, we consider the conditions $\theta_X \neq 0$, $\theta_{\mu_B} \neq 0$ and $\theta_{m_B} \neq 0$ respectively. The results show θ_X can give large contributions, even reach the experiment upper bound ($5 \times 10^{-17}e.cm$) for c EDM. The effects produced from θ_{m_B} and θ_{μ_B} are at the order of $10^{-21}e.cm$, which are much smaller than those from θ_X . For the t quark EDM the CP-violating phases θ_3 , θ_μ and θ_X are studied. In both $\theta_X \neq 0$ and $\theta_3 \neq 0$ conditions, we find d_t at the order of $10^{-17}e.cm$. Especially for nonzero θ_3 with $m_{\tilde{g}}$ near its lower bound, t quark EDM can reach $10^{-16}e.cm$ and even larger. They are both larger than the results for $\theta_\mu \neq 0$.

In BLMSSM, at one loop level there are three type contributions (1. the virtual X and exotic up-type quark, 2. baryon neutralino and up-type squark, 3. exotic up-type squark and \tilde{X}) to quark EDM beyond MSSM. For the contributions beyond MSSM, to obtain large d_c and d_t the CP-violating phase θ_X should be nonzero in our used parameter space. With

only $\theta_X \neq 0$, the nonzero contributions come from Eqs.(23)(25). In the Fig.4 $d_c \sim 10^{-17}e.cm$ and in the Fig.7 $d_t \sim 10^{-17}e.cm$, the EDMs d_c and d_t are of the same order of magnitude. In the other works, the EDMs d_c and d_t should be of different order. What is the reason in this work? The reason can be found from the couplings in Eqs.(13,14). The coupling constants λ_1 and λ_2 are important parameters. In our numerical calculation, we adopt that the values of $\lambda_1(\lambda_2)$ for c quark are same with the values of $\lambda_1(\lambda_2)$ for t quark. That is to say, for the up type quark generation 2 and generation 3, the adopted values of $\lambda_1(\lambda_2)$ are the same.

From these numerical results and our previous work on neutron EDM, we find θ_3 and θ_X are important CP-violating phases. $\tan\beta$, Y_{u4} , Y_{u5} , $m_{\tilde{g}}$, m_Q^2 , m_U^2 , λ_1 , λ_2 , V_{Bt} are also important. In the whole, our numerical results are large to be detected in the future. The work can confine the parameter space in this model and possess meaning to the relevant experiments for c and t quark EDMs.

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